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A Home-Made Automatic Noise-Figure Measuring System

This two-part article describes an automatic noise-figure measuring system that allows rapid alignment for minimum noise figure. If the noise source is calibrated, it is also possible for absolute noise-figure measurements to be made. The frequency range of the measuring system is determined by the noise source. The described measuring system possesses a 144 MHz input, but it is easily possible for it to be changed to other frequency ranges such as 29 MHz, 10.7 MHz or even AF. The noise figure is read off directly in dB on the meter, as can be seen in the photograph of the author's prototype in Figure 1.

In contrast to most noise-figure measurements

such as the 3 dB method or Y-factor method, that only allow a time-consuming alignment process, the measuring system described here allows automatic measurements to be made in a rapid sequence, which means that the results of the alignment can be seen immediately. In practice, such a measuring system is very useful, especially in conjunction with passive mixers; however, also in conjunction with converters and preamplifiers using expensive input transistors, one will soon see that the costs of such devices are only worthwhile if they can be aligned to optimum on a noise-figure measuring system. In order not to bore our practical readers, we are going to keep the theory of noise-figure measurements to a minimum.

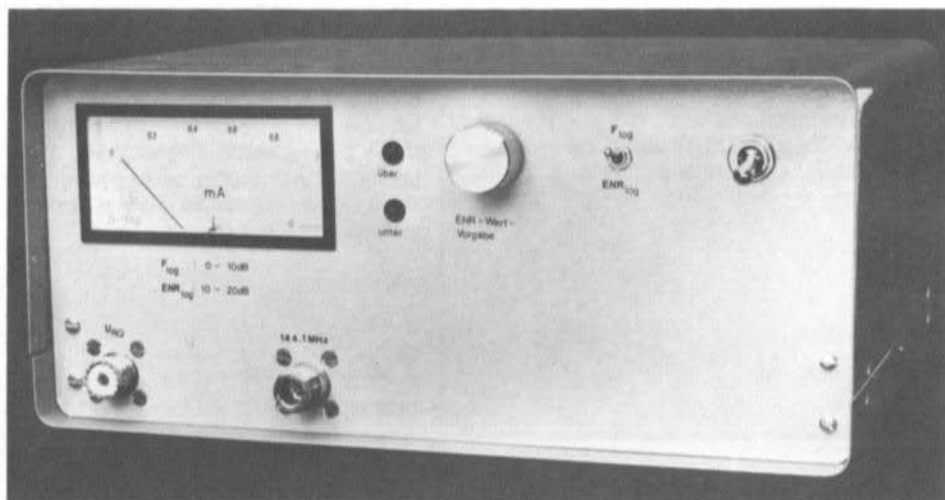


Fig. 1: Photograph of the author's prototype of the noise-figure measuring system

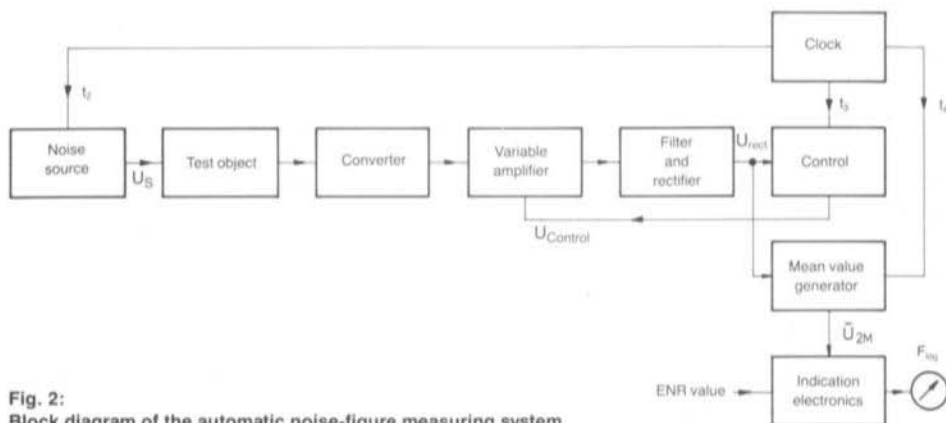


Fig. 2:
Block diagram of the automatic noise-figure measuring system

1. MEASURING TECHNOLOGY

The noise figure is a criterion for the sensitivity of a system. However, it does not exist in the same manner as voltage, current, or power. This means that it can only be measured indirectly. The measuring technology has not changed considerably subsequent to the IEEE-standardization in 1957.

During the measurement, the test object is excited by two known noise levels one after another, and the output power is determined. These two levels then allow the noise figure to be calculated (1).

The term „Excessive Noise Ratio“ – ENR – specifies the noise source with which the system is to be driven.

$$\text{ENR}_{\log} = 10 \lg \left(\frac{P_2}{P_1} - 1 \right)$$

P_1 : Available output power from the source in state 1 (passive)

P_2 : Available output power from the source in state 2 (active)

Both power levels are mean noise powers and are referred to the bandwidth B.

If P_1 corresponds to the power that a resistor

provides at ambient temperature (1 kT_0), the noise figure can be calculated according to the following equation:

$$\text{NF}_{\log} = \text{ENR}_{\log} - 10 \lg \left(\frac{P_{2M}}{P_{1M}} - 1 \right)$$

P_{1M} : Output power of the test object when driven with P_1

P_{2M} : Output power of the test object when driven with P_2

The measuring technology that can be derived from this equation is used in virtually all automatic noise-figure measuring systems. The best systems achieve accuracies of $\pm 0.2 \text{ dB}$ using this system.

1.1. SPECIAL FEATURES OF THE DESCRIBED METHOD

The block diagram of the system is shown in **Figure 2**; **Figure 3** shows the time-plan of the measurement. The „clock“ switches the noise source at a speed of 50 ms. The source is passive during the period t_1 , and is active during t_2 . The output noise powers of the test object are amplified and converted to AF-level. It is now possible for the noise levels to be determined using the mean value of the noise voltages.

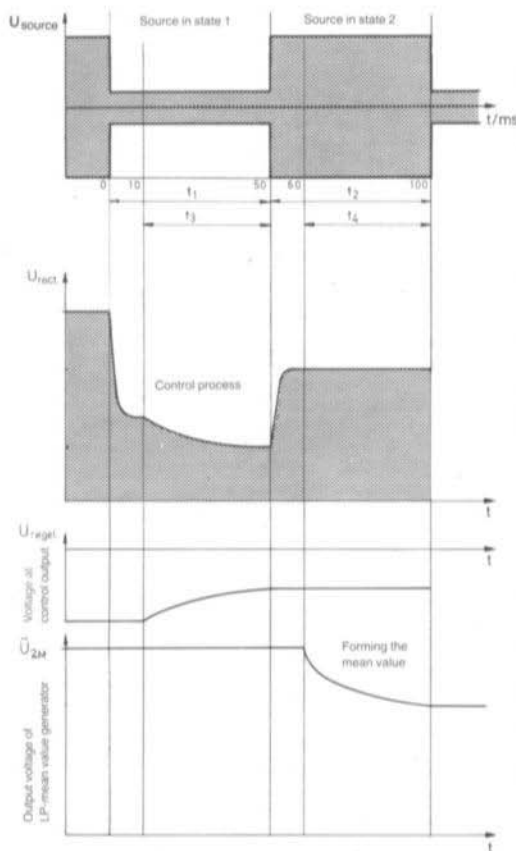


Fig. 3:
Time-plan of a measurement

$$\bar{U}_{1M} = \sqrt{\text{const} \times P_{1M}}$$

$$\bar{U}_{2M} = \sqrt{\text{const} \times P_{2M}}$$

$$NF_{\log} = ENR_{\log} - 10 \lg \left[\left(\frac{\bar{U}_{2M}}{\bar{U}_{1M}} \right)^2 - 1 \right]$$

\bar{U}_{1M} : Mean value of the AF-noise voltage when the source is in state 1; (passive)

\bar{U}_{2M} : Mean value of the AF-noise voltage when the source is in state 2 (active)

In order to ensure that the transient behaviour on switching the noise source on and off does

not have an adverse effect on the measuring results, the „mean values“ are only formed during the periods t_3 and t_4 . The formation of the mean value is achieved using a lowpass filter and an I-control.

The proportionality factor „const“ is determined via the variable amplifier so that U_{1M} has a defined value. This means that a fixed relationship exists between U_{2M} and NF_{\log} (equation 5) with the exception of the term ENR_{\log} .

This relationship is taken into consideration in the evaluation electronics so that the noise-figure can be directly indicated.

It is difficult to give the accuracy of the described system as a single number. The accuracy of the noise source has a considerable influence. In the case of the following typical values, the maximum error caused by stages subsequent to the test object is less than 0.4 dB:

$$ENR_{\log} = 17.0 \text{ dB}$$

$$NF_{\log} = 2.0 \text{ dB}$$

$$V = 20.0 \text{ dB}$$

$$V = \text{Gain of the test object}$$

A detailed discussion of possible errors, and measures which can be taken to increase the measuring accuracy are to be discussed in an appendix.

2. BRIEF DESCRIPTION OF THE CONSTRUCTION

As can be seen in **Figure 4**, the measuring system can be split into six modules:

Noise source

Receive converter

Demodulator and variable amplifier (RMG 03)

Oscillators

Control electronics (RMG 02)

Read-out electronic and reference-voltage generator (RMG 01)

Figures 5 and 6 show the prototype from above and below. The individual modules are to be described individually in the following sections.

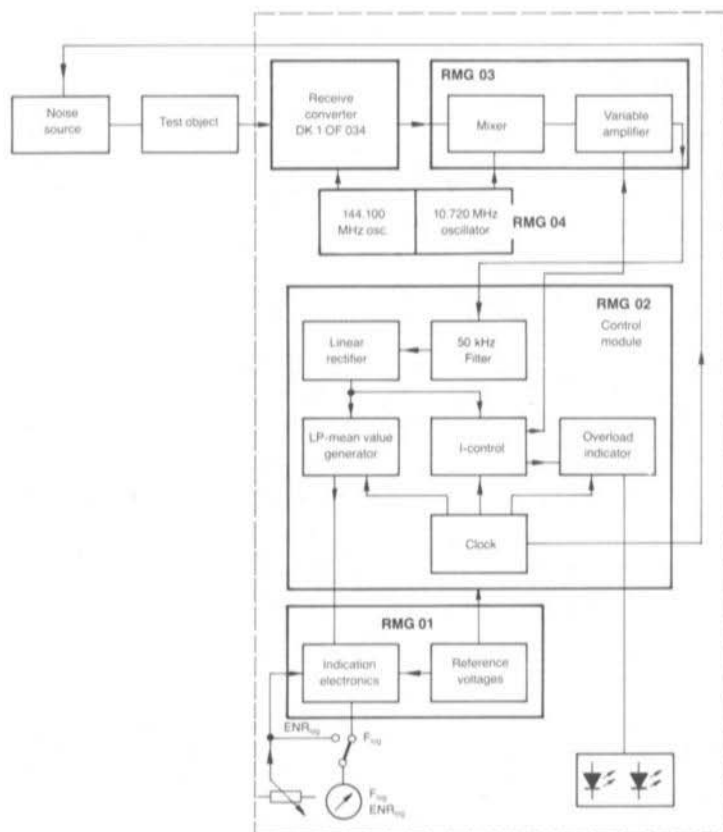


Fig. 4:
Modules of the
noise-figure
measuring system

3. NOISE SOURCE

The noise source can be built up in a similar manner to that described in (2). It is only necessary for it to be extended so that the switching between P_1 and P_2 can be made electronically (Figure 7).

It is advisable for the noise source to be installed in a separate case so that it can be directly con-

nected to the test object. This ensures that measuring errors due to attenuation, reflection, and transformation in the additional connectors and cables will not falsify the measuring results.

The knowledge of the ENR-value is very important for absolute noise-figure measurements. It can be determined by comparing it with calibrated noise sources; for instance at a university, technical college or even other amateurs with calibrated sources.

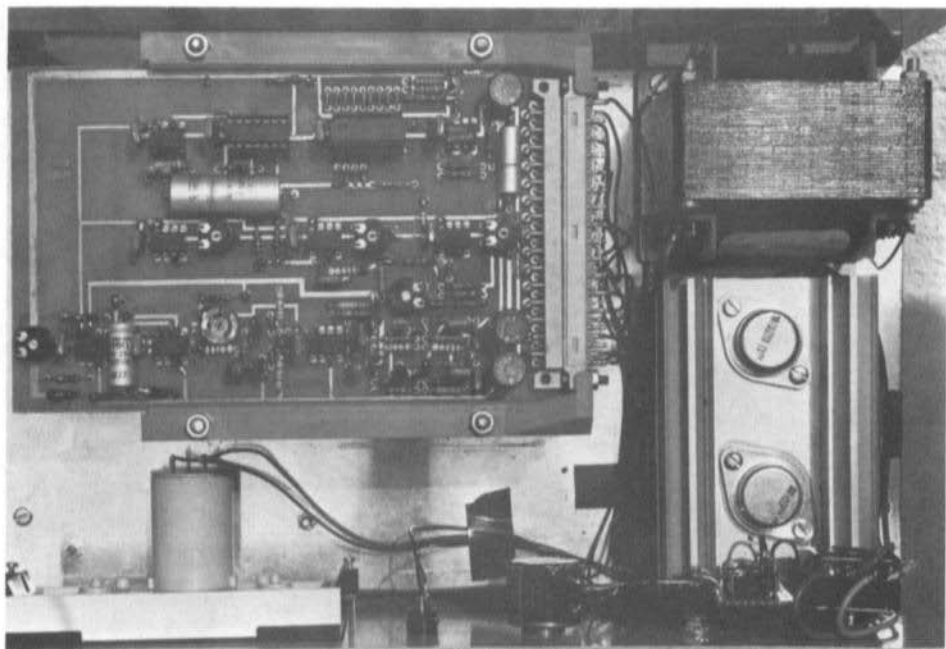


Fig. 5: Plug-in boards RMG 01 and 02 and power supply

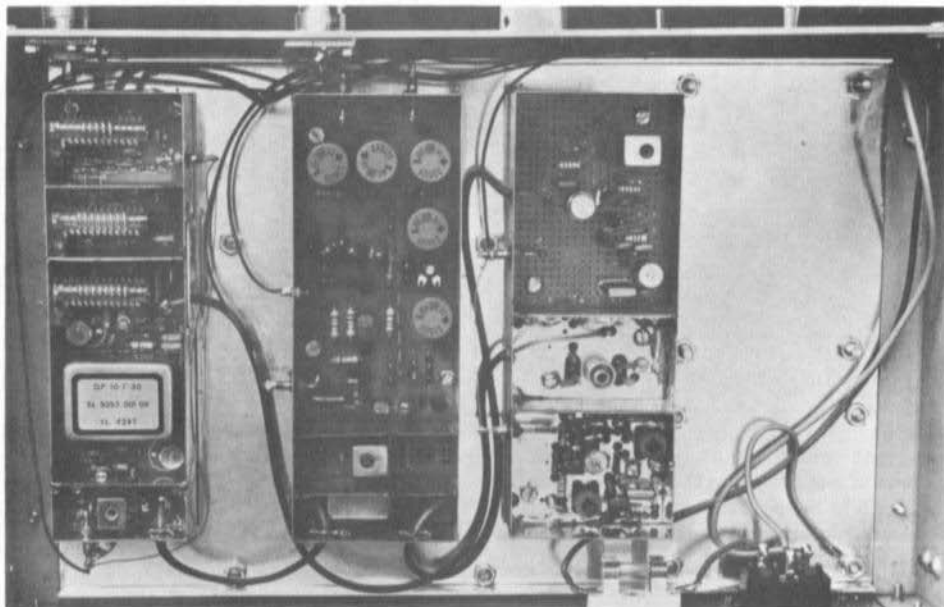


Fig. 6: The screened modules converter, RMG 03 and 04 on the lower side of the system

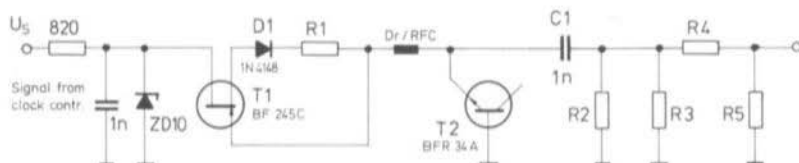


Fig. 7:
The noise-source is operated with a switched voltage of at least 12 V

4. RECEIVE CONVERTER

The input module DK 1 OF 034 described by J. Kestler in (3) is suitable for use in the noise-figure measuring system after carrying out a few modifications. **Figure 8** shows the modified circuit.

4.1. BANDWIDTH

The highest possible measuring bandwidth is required in order to measure the characteristic

value of the noise in a fast, **and** accurate manner. For this reason, measuring bandwidths of several MHz are often used for professional applications. If radio communications are made in this frequency range, usually screened cages are used. Since considerable radio communication is made on the amateur bands, and the radio amateur will hardly have a screened Faraday cage available, the author has chosen an RF-bandwidth of only 30 kHz.

The crystal filter XF-107B of the original description has been replaced by a 30 kHz crystal filter. Due to the different impedance of the filter, it is necessary to increase the values of resistors R 1, R 2 to 2 kOhm, whereas C 1 and C 2 are replaced by 30 pF trimmers.

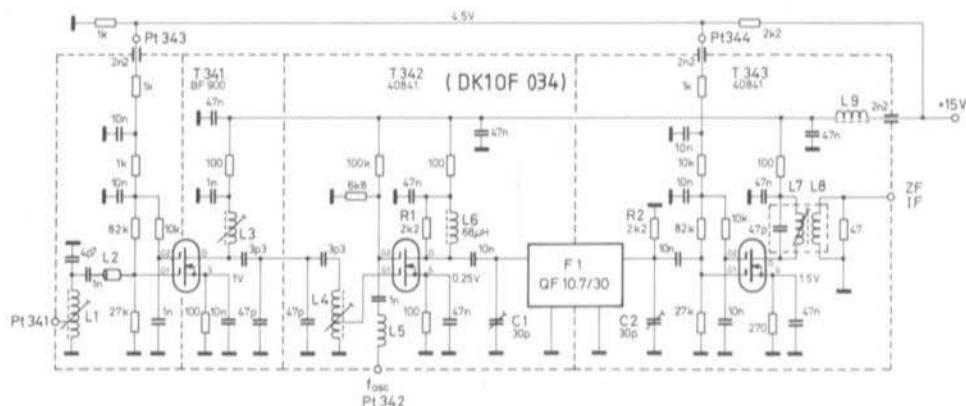


Fig. 8: A part of the circuit DK 10F 034 is used as receive converter



4.2. OUTPUT COUPLING

The FM-demodulator CA 3089 is not used during the noise measurements. The 10.7 MHz noise-signal is therefore coupled out after L 8 and the 47 Ohm resistor.

4.3. CONTROL

The gain of the input module DK 1 OF 034 can be influenced greatly with the aid of the control voltage U_C . However, module RMG 03 is responsible for the gain control in order to allow the use of other receive converters and to avoid the higher noise-figure that would be present when the gain was controlled down. For this reason, U_C is kept at a constant value via a voltage divider.

Although the noise figure of the input transistor was given to be 2 dB, we were only able to obtain a value of 4.5 dB after carefully aligning this converter.

5. THE DEMODULATOR AND AGC AMPLIFIER

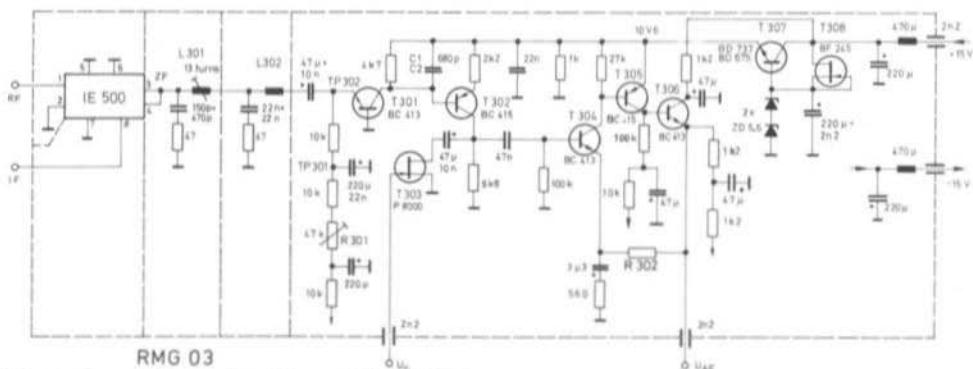
The demodulator and control module is

designated RMG 03. It is designed so that it can also be used with other receive modules. The noiseband (10.685 – 10.715 MHz) is converted to an AF-band of 5-35 kHz with the aid of the described receive converter and a 10.720 MHz oscillator.

5.1. CIRCUIT DESCRIPTION

Figure 9 shows the circuit diagram of the demodulator and AGC amplifier. The mixer IE 500 converts the noise band to AF-level. It is provided with two 50 Ohm matching filters connected in series at the IF-output which are provided to ensure that no RF-signals can be fed to the connected audio amplifier. The first stage of the AF-amplifier is also designed so that it represents a 50 Ohm termination. Since the noise voltage is in the order of several μ V under unfavourable conditions, a considerable amount of filtering is required for the voltage supply and operating point adjustment. For this reason, an additional voltage of approximately 10 V is stabilized and passed through two RC-links which are connected in series.

The lower cut-off frequency of the amplifier is designed to be 1 kHz in order to ensure that no measuring errors are caused by the 1/f noise of the transistor. The FET T2 is used as a variable resistor and allows the overall gain to be varied by approximately 40 dB.





5.3. SWITCHING ON AND ALIGNMENT

Before commencing alignment, one requires a voltmeter (approx. 10 kOhm/V), an oscilloscope, and an AF-generator (at least a 10 kHz square-wave generator with variable voltage divider).

The input U_C should be connected to a variable, negative voltage (e. g. via a 100 kOhm potentiometer between ground and -15 V). The internally stabilized voltage of 10.6 V should be checked after connecting the operating voltage. Resistor R 1 should be adjusted so that a voltage of -5.8 V is present at TP 1. Due to the large time constant of the filtering for the operating point voltage, the alignment can only be carried out slowly. For this reason, it takes several seconds after switching on for the stage to operate. The AF-generator is connected to TP 2 via a 1 MOhm resistor, and aligned to approximately 10 kHz. The voltmeter is now connected to U_C . A voltage of approx. -10 V is fed to U_C . The output voltage of the AF-generator is now set so that U_{AF} is not distorted. The gain between TP 2 and U_{AF} should be approximately 105. On slowly reducing the value of U_C , the gain will at first remain fairly constant, after which it will drop suddenly (Fig. 12). This voltage threshold U_{CT} should be noted. It is required for the alignment of the control circuit. A gain range of approximately 40 dB should be possible by varying the bias voltage.

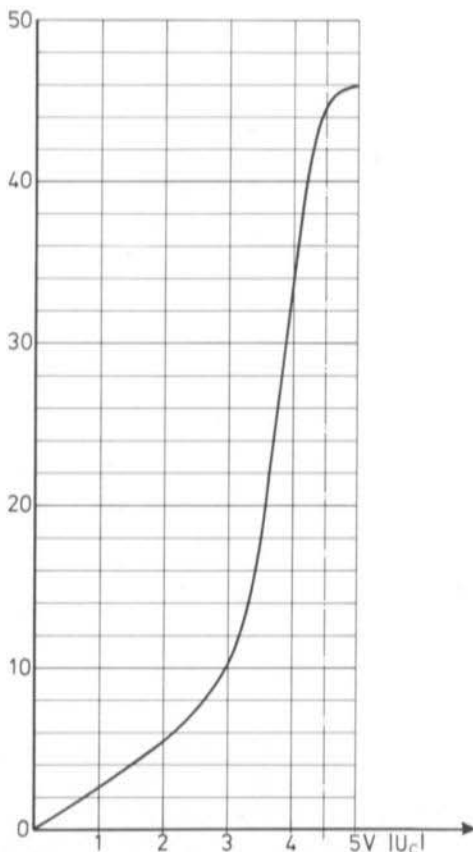


Fig. 12:
Gain as a function of the
control voltage

6. OSCILLATORS

A carrier of 133.400 MHz at 0 dBm is required for driving the receive converter. This can be achieved using a local oscillator circuit such as provided on module DJ 7 VY 002 by M. Martin in (4). Very few modifications are required:

- Q : 66.700 MHz
 - L 7: 7 turns (otherwise as described)
 - L 9: 5 turns (otherwise as described)
- The signal is coupled out after F 4.

The mixer of the RMG 03 is driven with a 10.720 MHz signal at a level of 7 dBm. The circuit described by F. Krug, DJ 3 RV in (5) can be used for this. Of course, one will not require the components for switching the oscillator.

Part 2 of this article is to describe the following modules:

- Control module RMG 02
- Indicator electronics, and reference voltage generator RMG 01



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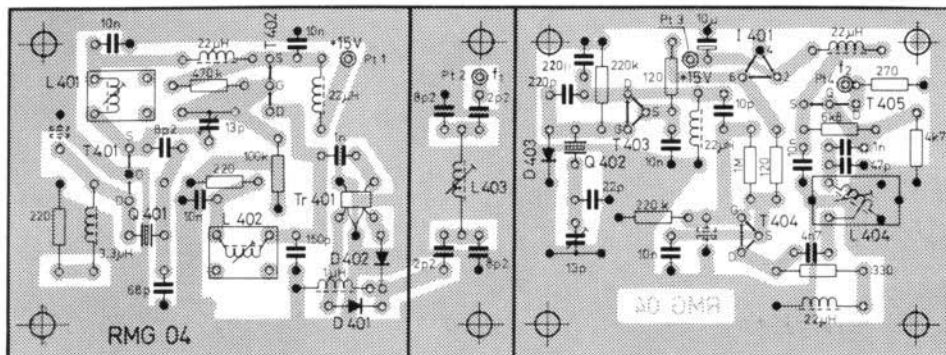


Fig. 14: Component locations on board RMG 04. A small chamber for the 133.4 MHz filter is to be seen in the center.

6.1. Oscillator Module

The circuit diagram of the two oscillators that were already mentioned in Part 1, are given in **Figure 13**. PC-board RMG 04 was developed to ease construction. The dimensions are 135 mm x 50 mm, and the board is therefore suitable for fitting in a standard metal case. The PC-board

should be completed according to the component location plan given in **Figure 14** and provided with screening panels.

6.1.1. Component Details, RMG 04

T 401, T 402, T 405: P 8002 (TI)
T 403: BF 256 B (TI)
T 404: BF 246 A (TI)
D 401 – D 403: HP 2800 or similar Schottky diode

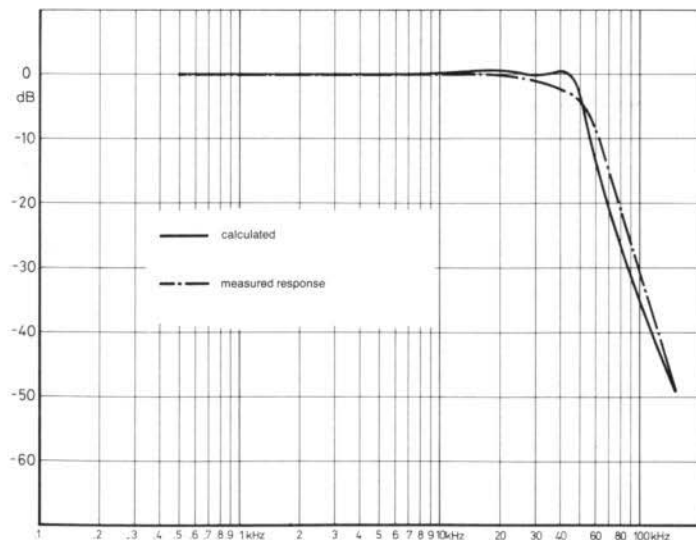


Fig. 16:
Frequency response
of the AF-lowpass
filter

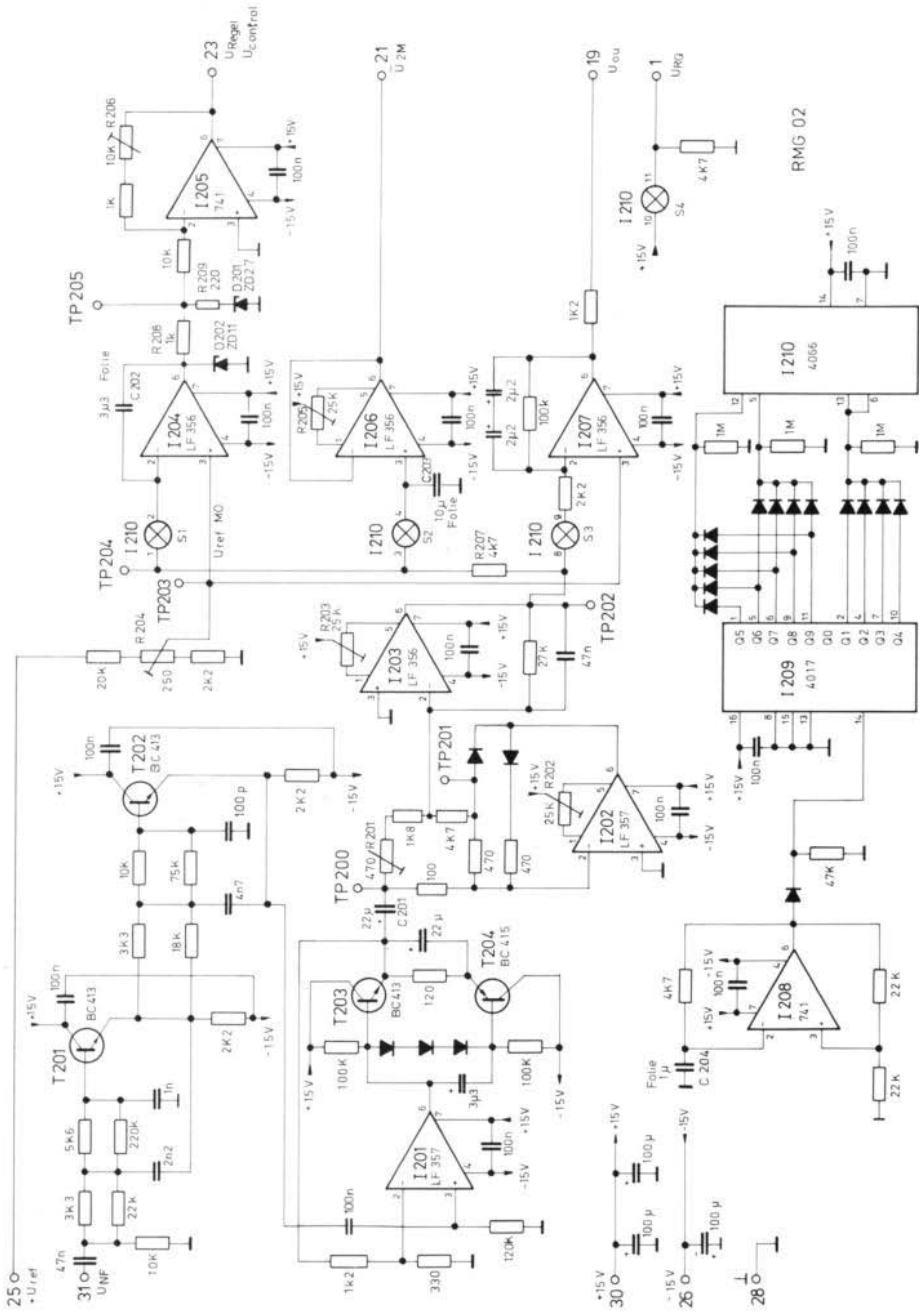


Fig. 15: Circuit diagram of the control module RMG 02



- I 401: REF-01 low-noise 10 V stabilizer
- L 401: 7 turns of 0.3 mm dia. enamelled copper wire, wound in a single layer in coil former D41-2165; do not use screening can!
- L 402: 2 turns, otherwise as L 401
- L 403: 5 turns of 0.8 mm dia. silver-plated copper wire, wound on a 7 mm former, self-supporting, mounted vertically to the board. A 5 mm coil former with VHF-core is provided in the coil
- L 404: 24 turns of 0.3 mm dia. enamelled copper wire with coil tap 6 turns from the cold end, using coil set D41-2165
- Tr 401: Double-hole ferrite core (Siemens B 62152-A8-X17) wound with 0.12 mm dia. enamelled copper wire: 4 turns at first, then 2 x 4 turns wound in a bifilar manner on top.
- 7 miniature chokes, spacing 10 mm
- 2 plastic foil trimmers 13 pF (Philips: yellow)
- 15 ceramic disk capacitors between 2.2 pF and 4.7 nF, spacing 2.5 mm
- 7 ceramic flat capacitors between 10 nF and 100 nF, spacing 5 mm
- 2 ceramic feedthrough capacitors
- 2.2 nF (value not critical), for solder mounting
- 1 tantalum electrolytic, 10 μ F/25 V
- 13 composite carbon resistors, spacing 10 mm
- 1 crystal 66.700 MHz in HC-43/U holder
- 1 crystal 10.720 MHz in HC-43/U holder
- 1 metal case 135 x 50 x 30 mm

The PC-board is designed so that the two oscillators can be built up and operated separately.

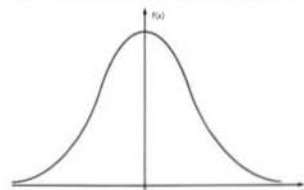


Fig. 17: Gaussian distribution of the momentary voltage of noise

7. CONTROL MODULE

7.1. Circuit Description

The control module whose circuit diagram is given in **Figure 15** has been designated RMG 02.

It represents the heart of the system.

The noise voltage U_N from module RMG03 possesses an upper limit frequency of 35 kHz in the described concept. The main selectivity is provided by the 10.7 MHz crystal filter. If one wishes to measure at 10.7 MHz (additional measuring input), and must do without the converter and crystal filter for this reason, it will be necessary for the main selectivity to be made in the AF-range. However, this will only be possible when no carriers are in the vicinity of the intermediate frequency, and when the IF-selectivity previous to the RMG03-module is sufficiently good. In this case, one will obtain two different noise spectra converted into the AF-range. The RF-bandwidth is then twice as large as the AF-bandwidth. For this reason, the AF-bandwidth is limited in a defined manner using a lowpass comprising transistors T201 and T202. This is a fourth-order filter which is designed for an upper limit frequency of 50 kHz. **Figure 16** gives the calculated and measured characteristics.

The distribution density of the momentary voltage of thermal noise corresponds to a Gaussian or normal distribution curve, as can be seen in **Figure 17**. Since this will disappear in the case of no voltage, this will mean that many high momentary voltages can appear, which must be processed by the measuring chain. Of course, real amplifiers, converters, etc. have only finite large-signal capabilities and will falsify the characteristic noise parameters. Since the effect of limiting is of extreme importance during noise-power measurements, an error curve has been given in **Figure 18**.

The rectifier must operate linearly in the whole frequency range ($f_{\max} = 50$ kHz) and in a wide voltage range, in order to ensure that the correct noise figure can be determined.

As non-linear element, it is especially critical in

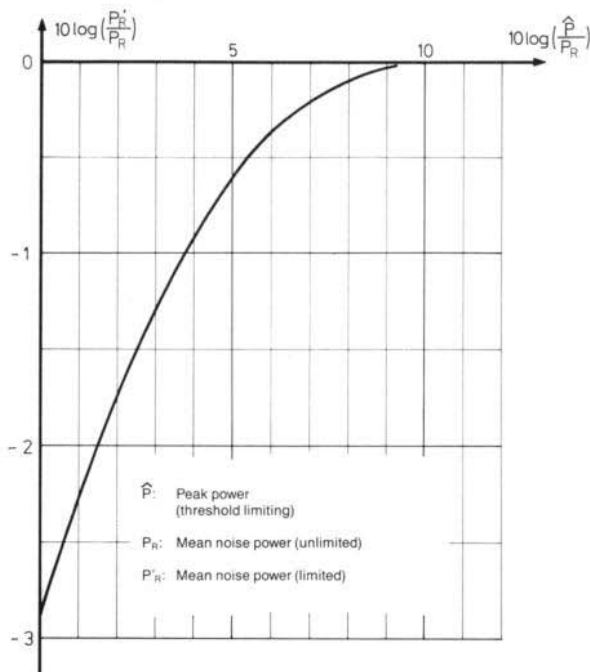


Fig. 18:
The diagram shows the effect of limiting when measuring noise power

the case of voltage peaks. A circuit has been realized with I201, I202, I203, and the impedance converter T203, and T204 which corresponds to that given in (1). The fast operational amplifier LF357 with its FET-inputs provides useful characteristics here. Amplifier I203 has been provided with low-pass characteristics in order to smooth the voltage peaks before further processing. For this reason, it is possible to use the slower, but more stable type LF356 here and in the rest of the circuit.

The clock generator I208 provides the C-MOS decimal divider I209 with a 100 Hz clock pulse. The control signals for the C-MOS switches are generated via a diode network in I210. A measuring cycle has a duration of approximately 100 ms. According to Part 1, Figure 3, the measuring process is made as follows:

The C-MOS switch S_4 opens during t_1 , and the noise source will output a passive P_1 . Approximately 10 ms afterwards, switches S_1 and S_3 will also close. The control is now active: In other

words it generates a voltage, which drives the amplifier (inverted in I205) so that \bar{U}_{IM} is equal to 1 V. A difficulty exists here due to the statistic variations of the noise voltage, which means that the nominal value will never be exactly maintained. This will be seen as fluctuations of the reading. For this reason, an optimum must be found in the design of the control circuit: It should be fast in order to be able to compensate for gain variations, e.g. during alignment processes, and should be slow in order to average the noise. This is not difficult at constant, low-signal parameters of the control circuit. A simple calculation shows that the relationship between gain and control voltage must be exponential in order to obtain a low-signal behaviour independent of the operating point. In the case of module RMG 03, the relationship is different – see Part 1, Figure 12. Due to another nonlinearity (R208, R209, and D201 between control and amplifier-control voltage input), it is possible for the overall characteristic to be at least approximately brought into the required form.

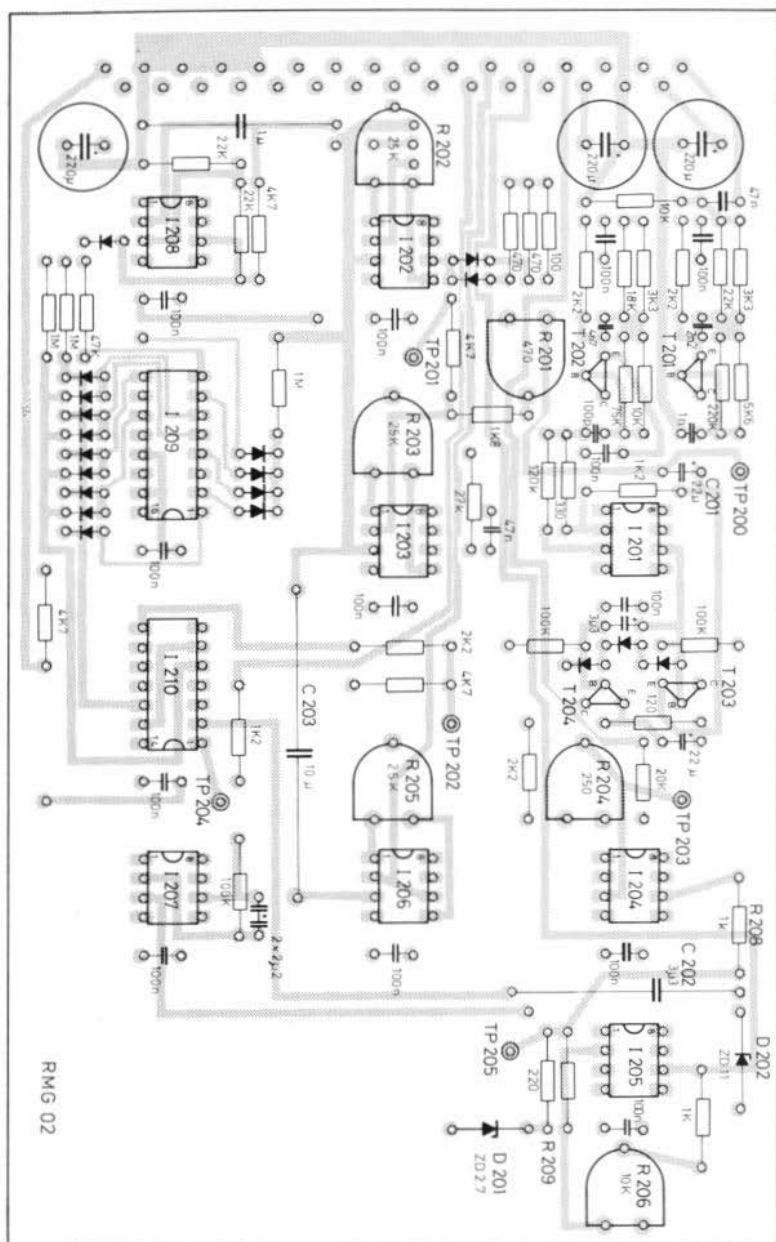


Fig. 19: Component location plan on the control board RMG 02



If the required gain cannot be obtained, the control voltage is limited by D202. The remaining deviation is registered in I207, and the error of the measuring result is indicated on the front panel using an LED. If the input level is too great, U_{out} will be in the order of -15 V , and will be approximately $+15\text{ V}$ if the level is too low.

After period t_3 , switch S_4 will close, which in turn opens S_1 and S_3 . The noise generator is now active, and the control voltage remains constant. After a further 10 ms, S_2 will close: I6 will operate as "mean value generator". Similar considerations as were made in the case of the control circuit are also valid for determining the time constant of the mean-value generator. After completing the measuring cycle, all switches are reopened. I207 will now operate as a scanning – hold link; \bar{U}_{2M} remains stored until the next mean-value is formed (t_4).

7.2.

Construction

The double-coated PC-board RMG 02 has been designed for accommodating this circuit. The dimensions are that of a Euro-board and it can be provided with a 31-pin connector. The module should be completed according to the component location plan given in **Figure 19**. It is only capacitor C201 that is only mounted during the alignment process.

7.2.1. Component Details for RMG 02

T201 – T203:	BC 413 or other silicon NPN AF-transistor
T204:	BC 415 or other silicon PNP AF-transistor
D201:	2.7 V zener diode
D202:	11 V zener diode
19 diodes:	1 N 4151 or other silicon switching diodes

I1, I2:	LF 357 N very fast operational amp. with FET inputs (Siemens etc.)
I3, I4, I6, I7:	LF 356 N fast operational amp. with FET inputs (Siemens etc.)
I5, I8:	741, TBA221 B operational amp. (Siemens, Fairchild, NS)
I9:	4017 decade counter/divider (C-MOS)
I10:	4066 quadruple switch (C-MOS)
C201:	22 $\mu\text{F}/25\text{ V}$ tantalum electrolytic (drop-type)
C202:	3.3 $\mu\text{F}/25\text{ V}$ or 63 V plastic foil capacitor (spacing 25 mm)
C203:	10 $\mu\text{F}/25\text{ V}$ or 63 V plastic foil capacitor (spacing 40 mm)
C204:	1 $\mu\text{F}/25\text{ V}$ or 63 V plastic foil capacitor (spacing 25 mm)
	4 pcs. ceramic capacitors between 100 pF and 4.7 nF; spacing 2.5 mm
	15 pcs. ceramic flat capacitors 47 nF and 100 nF; spacing 5 mm
	5 pcs. tantalum electrolytics (spacing 2.5 mm)
	3 pcs. aluminium electrolytics, round; spacing 5 mm
	6 pcs. trimmer potentiometers, horizontal mounting, spacing 10/5 mm
	40 pcs. composite carbon resistors, spacing 10 mm
	1 31-pin connector (DIN 41617 Siemens etc.)

Figure 20 shows the author's prototype which did not use a PC-board with through-contacts.

7.3.

Connection and Alignment

On connecting the operating voltage, the circuit takes approximately 53 mA of the positive voltage, and 56 mA of the negative voltage. The 100 Hz squarewave signal at I208/6, and the control voltages for the C-MOS switches can be checked with the aid of an oscilloscope. If everything is operating correctly, the signals given in **Figure 21** should be present at I210.

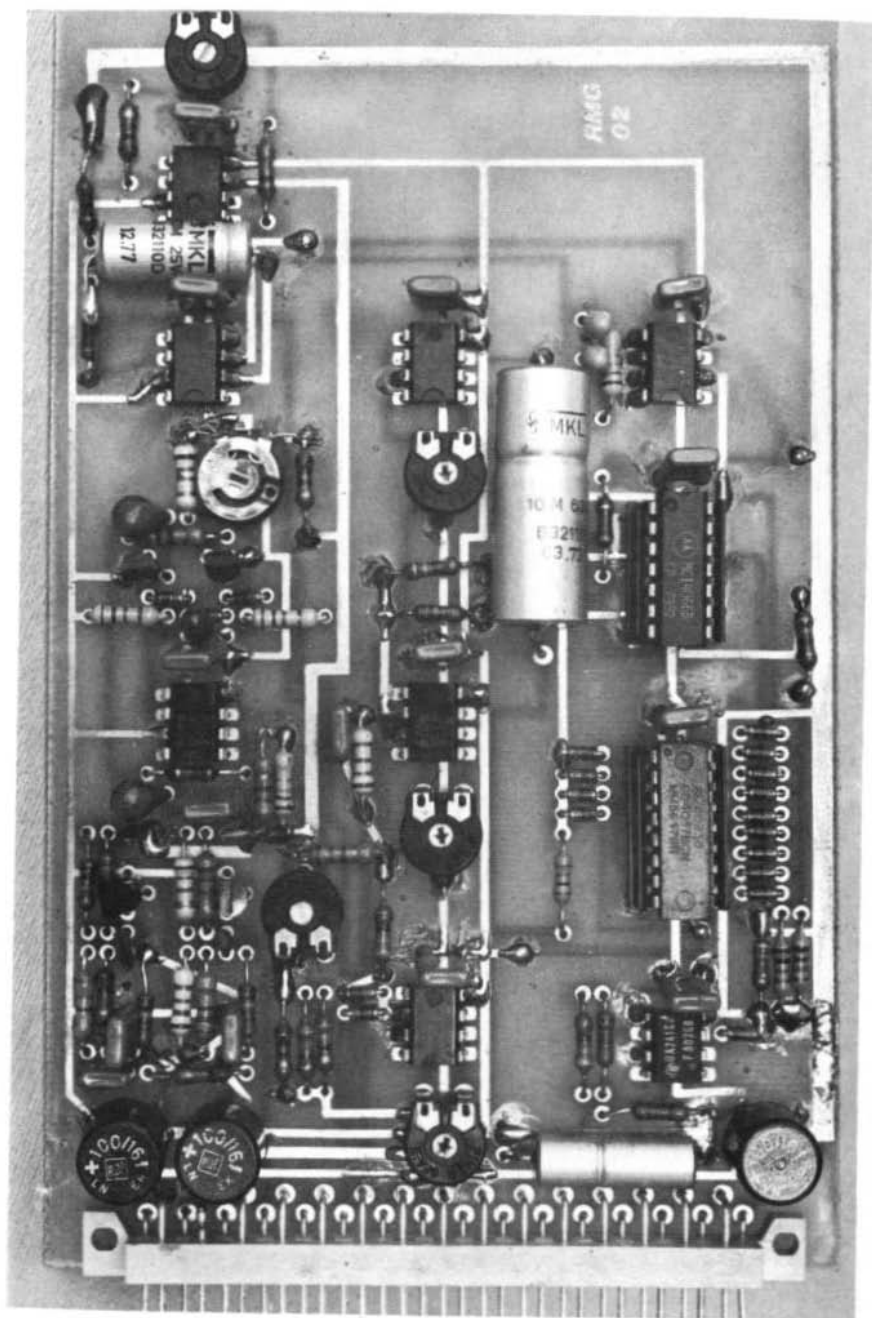


Fig. 20: The 3 large plastic foil capacitors will be seen on PC-board RMG 02

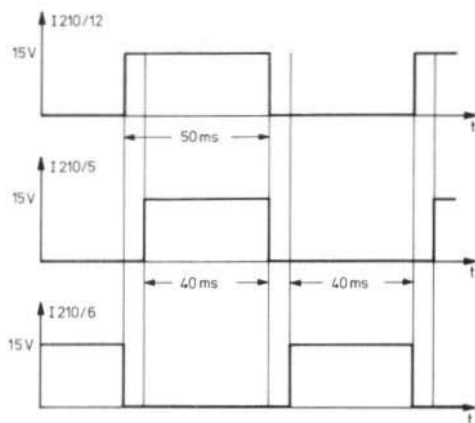


Fig. 21:
Control voltages for the C-MOS switches on RMG 02

Firstly align the offset and then the balance at the rectifier. This is made by grounding TP200, and aligning the operational amplifiers I202 (test point TP201) and I203 (test point TP202) to zero with the aid of R202 and R203. After this, connect a floating voltage source of approx. 0.7 V (battery and voltage divider) between TP200 and ground. A voltage of approximately 10 V should be present at TP202. While continuously changing the polarity of the voltage at TP200, R201 should be adjusted so that the output voltage remains independent of the sign of the input voltage.

The offset of I206 is compensated with the aid of R205 with C203 bridged.

The frequency response of the 50 kHz filter can be checked after soldering C201 into position by connecting an AF-generator to U_N and a voltmeter to TP202.

Potentiometers R204 and R206 are not aligned until carrying out the final alignment process.

8. READOUT ELECTRONIC AND REFERENCE VOLTAGE CIRCUIT RMG 01

The relationship between F_{log} , ENR_{log} , and \bar{U}_{2M}

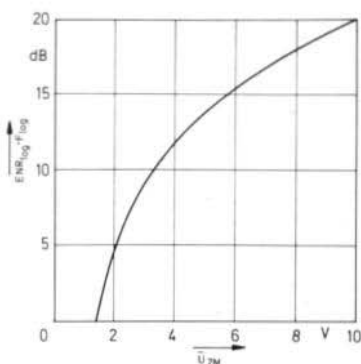


Fig. 22:
This characteristic of the readout-electronics allows F_{log} to be indicated on a linear meter scale

according to equation 5 (Part 1) is given in Figure 22.

This characteristic must be taken into consideration if \bar{U}_{2M} is to be processed in an electronic circuit in such a way that F_{log} is to be indicated in a linear manner.

With the aid of a computer program it was possible to approximate the characteristic $F_{log} - ENR_{log}$ in the range of -1 to -20 dB with the aid

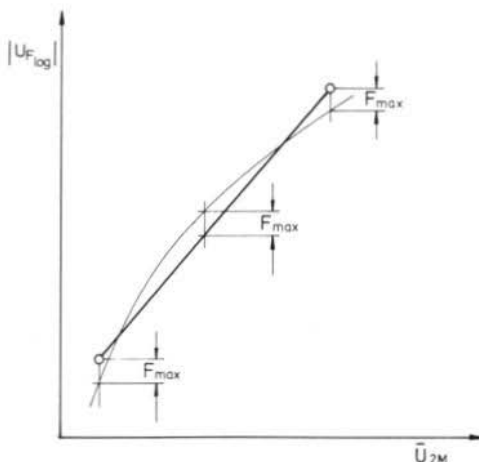


Fig. 23:
Principle of the straight-line approximation;
showing 1 straight line between two positions



\bar{U}_{2M}/V	$(F_{log} - ENR_{log})/dB$		$U_{F log}/V$
	exact	approx.	
1.500	- 0.97	- 1.03	- 0.514
1.790	- 3.43	- 3.49	- 1.746
2.230	- 5.99	- 6.05	- 3.024
2.890	- 8.66	- 8.72	- 4.362
3.860	- 11.43	- 11.49	- 5.745
5.250	- 14.24	- 14.30	- 7.151
7.220	- 17.09	- 17.15	- 8.573
9.990	- 19.95	- 20.01	- 10.004

Table 1:
Specifications of the bend points and voltage
standardization of $F_{log} - ENR_{log}$

of seven straight-lines, so that the maximum error was less than 0.06 dB. The principle of the straight-line approximation is shown in **Figure 23**. **Table 1** provides the specifications of the individual points and the voltage standardization of $F_{log} - ENR_{log}$ (0 to -20 dB corresponds to 0 to -10 V).

8.1. Circuit Description

The polygon characteristic is realized by superimposition of individual lines (see **Figure 24**). A partial circuit is given in **Figure 25** that generates the individual bent functions. Since 0 V (virtually ground) is present at the minus-input of the first operational amplifier, the following is valid for I_A , I_B , and I_C :

$$I_A = -\frac{U_{ref}}{R_2} \quad I_B = \frac{\bar{U}_{2M}}{R_1}$$

$$I_C = I_A + I_B = \frac{\bar{U}_{2M}}{R_1} - \frac{U_{ref}}{R_2}$$

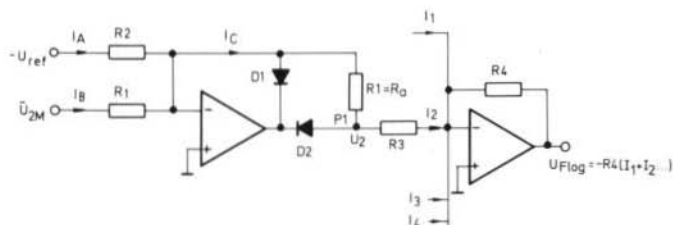
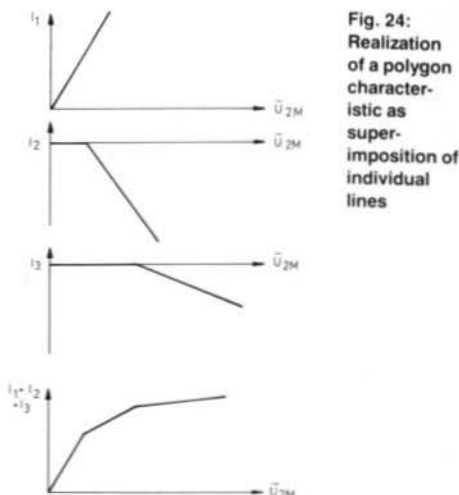


Fig. 25:
Circuit for an individual
bend function



As long as $\bar{U}_{2M} < (R_1/R_2) \times U_{ref}$, I_C will be positive and D1 will conduct, whilst D2 will be blocked. Point P1 is thus only connected via R_A and R_3 to the minus-inputs of the operational amplifiers.

$$U_2 = 0 \\ I_2 = 0$$

As soon as \bar{U}_{2M} exceeds the threshold value $(R_1/R_2) \times U_{ref}$, the sign of I_C will be inverted. The current will now flow via resistor R_A .

The following is valid:

$$U_2 = -I_C R_A = \frac{R_A}{R_2} U_{ref} - \frac{R_A}{R_1} U_{2M} \\ = \frac{R_1}{R_2} U_{ref} - U_{2M}$$

$$I_2 = \frac{U_2}{R_3} = \frac{1}{R_3} \frac{R_1}{R_2} U_{ref} - \frac{1}{R_3} U_{2M}$$



Metallfilm 1%



The second operational amplifier sums I_2 , and I_1, I_3, \dots which are generated in a similar manner and forms

$$U_{F \log} = -R_4 (I_1 + I_2 + I_3 + \dots)$$

Polygon characteristics can, of course, also be realized in a less complicated manner than when using the given circuit, but are far more complicated with respect to the calculation and alignment. **Figure 26** shows the circuit diagram of the readout electronics and reference voltage generator. **Table 2** shows the calculated resistance values for the linearization.

R 100 = 17078 Ω	R 107 = 16641 Ω
R 101 = 2355 Ω	R 108 = 25907 Ω
R 102 = 55866 Ω	R 109 = 24144 Ω
R 103 = 7456 Ω	R 110 = 19048 Ω
R 104 = 44843 Ω	R 111 = 34521 Ω
R 105 = 11380 Ω	R 112 = 13850 Ω
R 106 = 34602 Ω	R 113 = 48660 Ω

Table 2: Calculated values

Since the offset error of the operational amplifiers I101 to I106 has virtually no effect, the accuracy that can be obtained with the calculated circuit is virtually only dependent on the accuracy of the resistors. For this reason, each of the resistors given in **Table 3** are formed by series connection of two fixed and one variable

resistor. This allows the value of the potentiometer to be small, so that any possible misalignment due to shock etc. will have little effect.

The effect of aging of the resistors was checked in the computer. If metal-film types (as are described here) are used for the 10 k Ω resistors, the error will increase by approximately 0.04 dB. A more favorable result will be obtained when all resistors are metal-film types. In order to ensure the full measuring accuracy over a longer period of time, it is advisable for the alignment to be checked annually.

The operational amplifiers I108 and I109 generate the reference voltages of ± 10 V.

8.2. Construction

The PC-board for the readout and reference circuits is single-coated. The dimensions are standard Euro-board and a 31-pin connector can be used. **Figure 27** shows the component locations of this board, which has been designated RMG 01. If resistors having closer standard values and a lower tolerance are available (e.g. 1%), the PC-board can be equipped with these, so that potentiometers having a lower resistance value can be used.

Resistor No.	Trimmer Potentiometer Value	Resistor No.	Composite Carbon Value	Resistor No.	Composite Carbon Value
R 100a	2k2 (2k5)	R 100b	15k	R 100c	1k0
R 101a	220 (250)	R 101b	2k2	R 101c	47R
R 102a	2k2 (2k5)	R 102b	33k	R 102c	22k
R 103a	470 (500)	R 103b	3k3	R 103c	3k9
R 104a	4k7 (5k)	R 104b	39k	R 104c	3k3
R 105a	1k	R 105b	10k	R 105c	820R
R 106a	2k2 (2k5)	R 106b	33k	R 106c	470R
R 107a	2k2 (2k5)	R 107b	15k	R 107c	560R
R 108a	2k2 (2k5)	R 108b	22k	R 108c	2k7
R 109a	2k2 (2k5)	R 109b	22k	R 109c	1k0
R 110a	2k2 (2k5)	R 110b	18k	R 110c	0
R 111a	2k2 (2k5)	R 111b	33k	R 111c	390R
R 112a	1k	R 112b	10k	R 112c	3k3
R 113a	4k7 (5k)	R 113b	39k	R 113c	6k8

Table 3: The resistance values for the linearization of $U_{F \log}$



8.2.1. Special Components for RMG 01

I101 – I109: 741 or TBA 221 B op. amp.

D101: 1N3155, temperature-compensated

8.4 V zener diode

12 diodes: 1N4151 or similar

9 ceramic flat capacitors 100 nF, spacing 5 mm

2 tantalum electrolytics: 22 μ F/25 V

18 trimmer potentiometers, horizontal mounting, spacing 10/5 mm.

Values: see circuit diagram and Table.

44 composite carbon resistors, 12 mm spacing.

Values: see circuit diagram and Table 3.

15 metal-film resistors, spacing 12 mm;

10 k Ω /1%

31-pin connector (DIN 41617 Siemens, etc.)

Figure 28 shows the photograph of the author's prototype. Resistors R...c are still mounted below the PC-board at that time.

8.3. Connection and Alignment

The current drain of a correctly operating circuit is approximately 33 mA in the positive branch and approx. 22 mA in the negative. For the following alignment processes, \bar{U}_{2M} is to be provided with a variable voltage of 0 – 10 V, for instance using a 1 k Ω potentiometer between ground and +15 V. The alignments should now be made according to **Table 4**. They are not critical, but are important in order to obtain the full accuracy of the noise measuring system. For this reason, the alignment should be made carefully with the aid of a good digital voltmeter and in the given sequence. It is advisable to carry out a preliminary alignment before carrying out the final alignment in order to assure whether all adjustments are possible. If this is not the case, this will

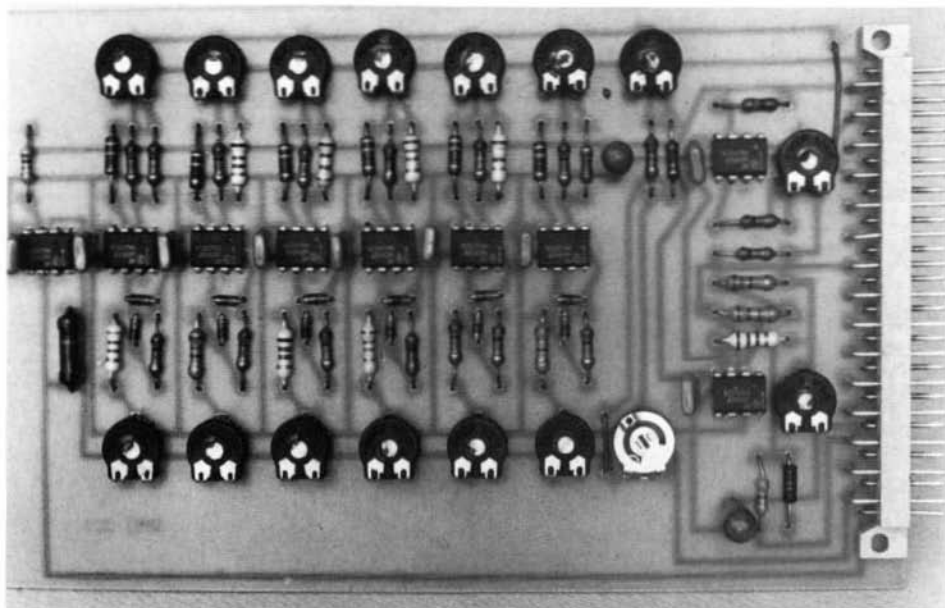


Fig. 28: This photograph of the author's prototype is still not in its final configuration



Preset voltage \bar{U}_{2M}	Instruction	Testpoint for voltmeter	Align	Alignment condition
	Connect 26 and 29			
Unconditioned		$+ U_{ref}$	R 114	$U_{ref} = 10.00 \text{ V}$
Unconditioned		$- U_{ref}$	R 115	$- U_{ref} = - 10.00 \text{ V}$
0.00 V		$U_{F \log}$	R 100	$U_{F \log} = 5.86 \text{ V}$
1.50 V		$U_{F \log}$	R 101	$U_{F \log} = - 0.514 \text{ V}$
1.79 V		TP 101	R 102	*
2.23 V		TP 102	R 104	*
2.23 V		$U_{F \log}$	R 103	$U_{F \log} = - 3.024 \text{ V}$
2.89 V		TP 103	R 106	*
2.89 V		$U_{F \log}$	R 105	$U_{F \log} = - 4.362 \text{ V}$
3.86 V		TP 104	R 108	*
3.86 V		$U_{F \log}$	R 107	$U_{F \log} = - 5.745 \text{ V}$
5.25 V		TP 105	R 110	*
5.25 V		$U_{F \log}$	R 109	$U_{F \log} = - 7.151 \text{ V}$
7.22 V		TP 106	R 112	*
7.22 V		$U_{F \log}$	R 111	$U_{F \log} = - 8.573 \text{ V}$
9.99 V		$U_{F \log}$	R 113	$U_{F \log} = - 10.004 \text{ V}$
	Loose conn. 26 – 29 connect 28 – 29			
Unconditioned		$U_{F \log}$	R 116	$U_{F \log} = - 5.000 \text{ V}$
Unconditioned	Connect 1 mA meter with " – " to $I_{F \log}$ and " + " to ground.	$U_{F \log}$	R 117	$I_{F \log} = - 1.00 \text{ mA}^{**}$

** Align using the meter that is to be used in practise.
Pay attention to correct position and zero adjustment.

Table 4: Values for the alignment of module RMG 01

mean that a previous alignment is not correct, or that the resistors in the voltage divider have too large a tolerance and must be exchanged or cor-

rected. After carrying out the final alignment, all adjustments should be fixed with lacquer so that no unwanted adjustment is possible.



precision of this meter is used twice in the measuring accuracy (firstly when adjusting the ENR-value and secondly on indicating the noise figure), it is advisable not to save with respect to this component. It is advisable to use a "class 1" meter which is not too small.

The 5 k Ω potentiometer allows the ENR-value alignment to be made easily if a 10-turn type is used.

9.3. Final Alignment

Potentiometers R204 and R206 on PC-board RMG02 must still be aligned. This is carried out with the 10.720 MHz crystal oscillator switched off. This means that the control circuit is broken and the control will go into limiting. The LED indicating too low an input level should now light up. Align resistor R206 so that voltage U_{control} (negative voltage) is adjusted to the value $U_{\text{control G}}$, which was determined in section 5.3.

A further precision alignment is now required. The same voltmeter should be used as was used for alignment of module RMG 01. It should have an input impedance of more than 10 M Ω , which is usual with DVMs. If required, an LF 356-impedance converter (with offset correction) can be used. The voltage at TP 203 should be aligned to 1.000 V with the aid of potentiometer R204. This alignment should also be fixed with lacquer. The 10.720 MHz oscillator is switched on again, after which the measuring system will be ready for operation if all modules are operating correctly.

The noise source is now connected to the control output U_{NS} and plugged to the 144.1 MHz measuring input "RF". It is now possible for the first noise alignment to be made: Namely that of the built-in receive converter as described by DK 1 OF. If the ENR-value of the noise source is known, it is possible for it to be set in switch position ENR_{log} with the aid of the potentiometer while observing the meter. The value 0 on the meter corresponds to ENR = 10 dB, and the full-scale deflection (100) corresponds to ENR =

20 dB. If an ENR-value of 16 dB is to be used, the potentiometer will be aligned for a reading of 60 scale units.

If, on the other hand, the ENR-value of the noise source is not known, firstly adjust any value that is able to produce a reading after switching to F_{log}. This allows the receive converter to be aligned for minimum noise figure. In the author's prototype using a DK 1 OF converter, a minimum noise figure of approximately 4.5 dB was obtained. If the ENR-value potentiometer is now adjusted until this noise figure is indicated (45 scale units), this means that the ENR-value is at least approximated in the 2m-band. It is possible afterwards to calibrate one's own noise-source by carrying out comparative noise figure measurements with precision equipment over the widest frequency range, and at the highest possible accuracy.

After the ENR-value and thus the noise figure of the measuring input is known sufficiently accurately, it is possible for the components of the second stage to be taken into consideration. For this, one requires the gain of the test object together with the following equation:

$$NF_{\text{tot}} = NF_1 + \frac{NF_2 - 1}{G_1}$$

where: NF_1 = noise figure of the test object (insert as a factor and not in dB!)

NF_2 = noise figure of the measuring input (e.g. 4.5 dB \approx 2.8)

G_1 = power gain of the test object, (also insert as factor)

Resistor R302 of PC-board RMG 03 was designed to have such a high value in order to carry out the noise alignment of the receive converter. In operation later, it is more favorable to reduce the gain: A value of 22 k Ω should be used for resistor R302.

10. FINAL NOTES

It would exceed the scope of this article if all pos-

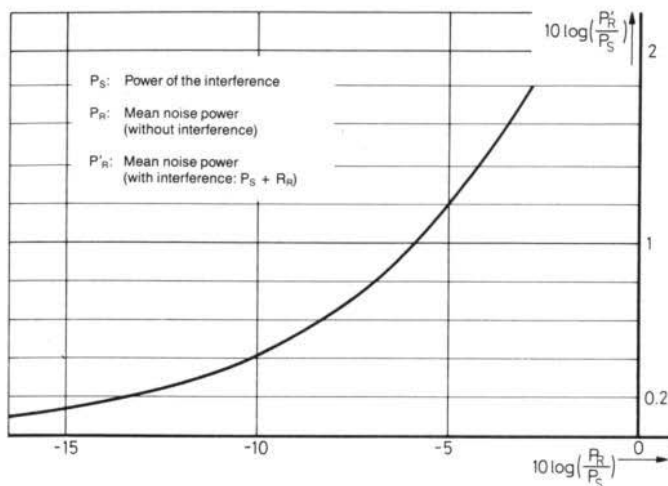


Fig. 30: An interference signal that is 6 dB weaker than the mean noise power will falsify a power measurement by 1 dB!

sible errors of noise figure measurements were to be mentioned. A previous article "Some Pitfalls in Noise Figure Measurements" (2) describes a large number of possible errors. At this point we would like to underline the extremely low value of the measured power levels:

$$\begin{aligned}
 1 \text{ kTo} \times 30 \text{ kHz} &= 0.4 \times 10^{-20} \text{ Ws} \times 30000 \text{ s}^{-1} \\
 &= 1.2 \times 10^{-16} \text{ W} \\
 &\approx -129 \text{ dBm}
 \end{aligned}$$

Figure 30 shows by how much interference signals must be **below the noise level** in order to obtain a certain accuracy during the measurements.

11. REFERENCES

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